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DescriptionPOWER TAKE-OFF CONTROL SYSTEM AND METHOD5 Technical Field

The present invention relates to a power take-off (PTO) control system and method for engaging a PTO clutch of a vehicle or work machine such as, but not limited to, an agricultural tractor, and more particularly, to a PTO control system that can effectively utilize both engine speed and PTO output speed values for determining a predicted and/or actual PTO load and other variable conditions which can effect engagement, and which can responsively calibrate the system for engagement under the load and other conditions and adaptively control applied acceleration and torque during the engagement.

Background Art

20 PTOs have long been used on many types of vehicles and work machines, including on agricultural vehicles such as combines and tractors, to provide power for equipment or implements, such as, for agricultural purposes, mowers, balers, forage harvesters and spreaders. Hereinafter, for the present purposes the terms vehicle and work machine are considered the same and are used interchangeably. PTOs are typically selectably connectable to a source of rotational power such as an engine of the vehicle by a clutch, such as an electrical or fluid controlled clutch, controlled by a clutch control system. Many known PTO clutch control systems have been developed over the years, and have operated under a variety of control strategies designed to provide desired features such as smooth engagement and to protect PTO shafts from catastrophic failure and

attached equipment during the clutch engagement from damage.

Typical of such known systems is the system of U.S. Patent No. 5,494,142, which discloses a PTO control system for vehicles, such as farm tractors including a PTO shaft, for supplying rotational motion to an implement of the type which may be stationary or towed by the tractor. Power is transferred to the PTO shaft by a clutch including an input shaft coupled to a power source and an output shaft coupled to the PTO shaft. The clutch transmits a maximum torque between the input and output shafts in response to a maximum clutch pressure and transmits a variable torque between the input and output shafts in response to a given clutch engagement pressure that is less than the maximum clutch engagement pressure.

Such control system includes a clutch control for engaging and disengaging the clutch in response to first and second control signals, respectively, and transmits a variable torque between the input and output shafts dependent upon a given clutch engagement pressure defined by the first control signals. The clutch engagement pressure is less than the maximum engagement pressure to limit the torque transfer between the input and output shafts by the clutch. The control system also includes a first transducer disposed to generate an input signal representative of the rotational speed of the input shaft, a second transducer disposed to generate an output signal representative of the rotational speed of the output shaft, and a control circuit. The control circuit is coupled to the clutch control, the first transducer, and the second transducer.

While such a control system has been of great value and effectiveness, it and other known control

systems have continued to experience difficulties when attempts are made to drive loads with the PTO which are extremely light or heavy. With such systems, one shortcoming is that no differentiation is made with
5 respect to the loads applied, be they very light or very heavy. With a light applied load, initial PTO shaft movement could occur at a relatively early time and modulation could be achieved over a relatively longer time period than necessary. With a heavy load, however,
10 initial PTO shaft movement would not occur until a later time, leaving much less time for modulation.

Also reference U.S. Patent No. 6,267,189, which discloses another known method for controlling engagement of a PTO clutch. In this method, during
15 engagement of the PTO, a control circuit continuously determines an actual acceleration of the PTO based upon the output shaft velocity, and generates control signals using a desired acceleration and the actual acceleration. The control circuit may continuously
20 determine the desired acceleration based upon the input speed signal. Alternatively, the control circuit may provide control signals to cause the torque transmitted through the clutch to increase at a rate depending upon the difference between the desired and actual
25 accelerations when the actual acceleration is more than a threshold proportion of the desired acceleration, and to cause the torque to increase at a rate independent of the difference when the actual acceleration is less than the threshold proportion.

30 Additionally, the system of U.S. Patent No. 6,267,189 may make adjustments that can adversely effect smooth clutch engagement. For instance, under some

heavy loading conditions, the resulting applied torque can result in substantial engine droop, but no, or very little, rotation or acceleration of the PTO output shaft. Under such conditions, a problem that can occur
5 is that the system may categorize the actual acceleration as below the threshold value, and proceed to cause the torque to increase at a faster rate, possibly resulting in problems such as rough engagement, engine stalling, and/or increased component wear and/or
10 damage, due to the high torque conditions.

Thus, what is sought is a PTO control system which overcomes one or more of the problems and shortcomings set forth above.

15 Summary Of The Invention

The present invention is directed to an improved system and method for controlling operation or engagement of a clutch for connecting a PTO of a vehicle in rotatably driven relation to a rotating power source
20 of the vehicle, such as an engine or transmission output, for overcoming one or more of the problems and shortcomings set forth above. According to one aspect of the invention, the system includes a controller for controlling an engagement pressure of the clutch, the
25 clutch including an input coupled directly or indirectly to the power source and an output coupled to the PTO, wherein the clutch will transmit a maximum torque between the input and output in response to a maximum clutch engagement pressure as controlled by the
30 controller, and will transmit a range of torque values between zero and the maximum torque in response to a range of clutch engagement pressures less than the

maximum clutch engagement pressure and a load condition on the PTO. Generally, the pressure will be increased at one or a succession of rates from a starting value, to a higher value at which the clutch will transmit a
5 desired level of torque which can be the maximum or some lesser torque. The clutch can be, for instance, a fluid or hydraulic clutch, and can include a valve such as a proportional clutch control valve for controlling delivery of pressurized fluid to the clutch for varying
10 the clutch pressure. The valve can be operated or controlled, for instance, by a control signal which can be a variable electrical current value, voltage value, a digital signal value, or the like. As an alternative, the valve can be pulse width modulated so as to be
15 capable of opening for varying periods for controlling clutch pressure. The system includes sensors for sensing a rotational speed representative of a rotational speed of the power source and of a rotational speed of the output, respectively, and outputting speed
20 signals representative of the sensed speeds to a processor of the controller. The controller includes a processor and is operable for storing and retrieving information in a memory and for outputting control signals to the valve for controlling the clutch
25 engagement pressure, for instance by varying electrical current or voltage, responsive to the speed signals and information contained in the memory, using an appropriate algorithm or operating strategy.

Generally, during operation the controller
30 will initiate clutch engagement by outputting a starting control signal or current value sufficient to cause the valve to begin increasing clutch pressure in a fill mode. This may be preceded by a short duration greater opening of the valve, known as a valve wake up. From
35 the starting signal or current value, the controller

will gradually increase the signal or current value during the fill mode such that the clutch will begin carrying torque, and thereafter increase the signal or current value such that the PTO output will begin to be
5 rotated. Then, in a modulation mode the controller will continue to increase the signal or current value, perhaps at a different rate or rates, which can be a higher rate, and which rate can change, such that the output will be accelerated so as to rotate at the same
10 speed as the input, which occurrence is known as lock-up. Subsequently, if the signal value or current at which the clutch locks up is not the maximum, the signals will typically be increased at an even faster rate to the maximum signal or current value in a ramp
15 mode.

As noted above, it has been found that the loading condition on the PTO can have a significant impact on the smoothness of the clutch engagement and the load on the drive train and power source. Clutch
20 wear, fluid temperature, and fluid system pressure are also factors in the smoothness of the engagement. Generally, as one problem, as a result of any combination of the above factors, if the starting control signal or current value for initiating
25 engagement is too high and/or the subsequent control signals during the fill mode and/or the modulation mode are increased too rapidly for an actual loading condition on the PTO, the engagement can be rougher and/or the rotational speed of the power source or
30 engine can be decreased or droop to an undesirable extent, and even stall. These are undesirable occurrences as they can cause problems including premature or increased wear on the clutch and other drive line components and even damage. If the starting
35 signal or current value is too low and/or the subsequent

signal values during the fill mode and modulation mode are increased too slowly for an actual loading condition on the PTO, then the engagement will likely be smooth, but the clutch will likely lock-up later than would be
5 necessary. Similarly, if the starting signal or current value is lower or higher than desirable for a given load condition or combination of the above factors, the later in time during the engagement process at which
10 determination of the existence of the condition and correction or compensation is made, the shorter the time available for implementing the correction or compensation.

To avoid or reduce the influence or impact of factors such as those set forth above, including load
15 conditions, clutch wear, fluid temperature and fluid system pressure, and/or to adapt to or compensate or correct for such conditions, the controller will determine the starting value for the control signal or current for commencing to fill the clutch based at least
20 in part on information stored in the memory relating to or derived from or determined during at least one previous engagement, particularly during the fill mode thereof. For an initial engagement wherein no or inadequate information relating to previous engagements
25 exist, such as for the first engagement of the clutch after the vehicle leaves the factory, a factory set or default starting value can be used. More preferably relating to subsequent engagements, the information used for the determination will include the initial control
30 signal or current value from at least one previous engagement at which the clutch began to carry torque, or a derivative thereof. The information is preferably determined or sensed from the occurrence of the first of two conditions, including a drop or droop in the
35 rotational speed of the power source, and the beginning

of rotation of the PTO output, if any. This information can be determined, sensed, or collected for any desired or required number of previous engagements, and can be processed, as required or desired for determining the starting control signal or current value for the next engagement.

According to one preferred aspect of the invention, the information from four previous engagements can be averaged and used as a reference for determining the starting control signal or current value for the next engagement.

According to another preferred aspect, if the information from the most previous engagement is beyond a predetermined range, or differs by more than a predetermined amount or in some predetermined manner from the information from the prior engagements, just the information from the last engagement can be used as the reference for determining the starting control signal or current value for the next engagement, or just the information from the previous engagements can be used.

With regard to the present engagement, the information used for determining the starting value can also be utilized for approximating loading and the other factors or conditions presently affecting the clutch, for adjusting the rate or rates of increase in the clutch pressure.

Thus, the determined information can serve several functions including, but not limited to, as an indicator or reference of loading and other conditions and factors affecting engagement of the clutch; that a selected starting control signal value is or is not appropriate for the present conditions; and as a factor for determining a starting signal or current value for subsequent engagements of the clutch.

Brief Description Of The Drawings

FIG. 1 is a schematic block diagram of a PTO
5 drive and control system;

FIG. 2 is a schematic block diagram
representative of the circuit configuration for a
controller of the control system;

FIG. 3 is a high level flow diagram of steps
10 for determining a starting control signal value
according to the invention;

FIG. 3A is a flowchart representative of the
general sequence of operation of a control system
embodiment;

15 FIG. 3B is a continuation of the flowchart of
FIG. 3A;

FIG. 3C is another continuation of the
flowchart of FIG. 3A;

20 FIG. 4 is a graphical representation of a
particular application of current/pressure control
signals to the hydraulic valve of the control system
over a period of time; and

FIG. 5 is a graphical representation of actual
and desired accelerations of a PTO shaft.

25 FIG. 6 is a flowchart representative of one
embodiment of the functionality of step 90 of the
flowchart of FIG. 3A.

FIG. 7 is a flowchart representative of one
embodiment of the functionality of step 98 of the
30 flowchart of FIG. 3B.

FIG. 8 is a graphical representation of actual
and desired speeds of a PTO and engine speed of an
agricultural vehicle during engagement of the PTO;

FIG. 9 is a flowchart representative of one embodiment of the functionality of step 94 of the flowchart of FIG. 3B; and

FIG. 10 is a flowchart representative of an additional operational steps that may be included in a point A in the operational sequence in FIG. 6.

Detailed Description Of The Invention

FIG. 1 depicts an embodiment of a power take-off (PTO) clutch and brake control system 10 for a representative work machine or vehicle, represented by an agricultural vehicle (such as a tractor schematically represented by the dashed line labeled 12) that includes, and is operable according to steps of, the present invention. With the exception of the PTO clutch control system 10, tractor 12 may be a conventional agricultural tractor of the type including a power source which is preferably an engine 14 having conventional accessories such as an alternator 16. Engine 14, in addition to providing power to the drive wheels (not shown) of tractor 12, provides the power to apply rotational motion to a multi-plate hydraulically actuated PTO clutch 18. Depending upon whether PTO clutch 18 is engaged, power from engine 14 may in turn be transmitted to an output shaft 32. Output shaft 32 is shown directly coupled to a 1000 RPM PTO (high speed PTO) shaft 33 and also is shown coupled to a 540 RPM PTO (low speed PTO) shaft 35 by a reduction gear 37. In alternative embodiments, high speed PTO shaft 33 may be of another speed rating such as 750 RPM. While, in alternate embodiments, high and low speed PTO shafts 33 and 35 may be provided at separate output terminals on tractor 12, preferably each PTO will be employed at a single output terminal (one PTO may be substituted for the other).

Control system 10 includes a controller 20 (including, e.g., a digital microprocessor such as the Intel TN83C51FA), a PTO on/off switch 22, an output clutch speed transducer 26, and a normally closed, 5 solenoid operated, hydraulic, proportional clutch control valve 28. Control system 10 also is coupled to alternator 16 and receives a signal therefrom representing the speed of engine 14.

The engine speed is equal to or, depending 10 upon gear reduction, a multiple or proportion of the speed of an input shaft 19 to PTO clutch 18 that receives power from engine 14 and transmits power to the clutch. In alternate embodiments, a signal representative of the speed of input shaft 19 (that is 15 directly representative of the speed of engine 14) may be obtained by way of an input shaft transducer 24 coupled to shaft 19 instead of alternator 16. Consequently, for purposes of this document, reference may interchangeably be made to the engine and/or its 20 speed or to the input shaft and/or its speed, with like effect, and treating the speeds as being alike although they may differ proportionally.

Transducers 24 and 26 may, by way of example and not of limitation, be variable reluctance sensors.

25 Alternator 16 and transducer 26 are coupled to digital inputs of controller 20 by, respectively, electrical conductors 21 and 29 and conditioning circuits 79 and 38, which may be integral to controller 20. (In alternative embodiments in which 30 signals regarding input shaft 19 are provided by transducer 24, an electrical conductor 25 along with conditioning circuit 38 may be employed.) Conditioning circuits 79 and 38 filter radio and other undesirable frequencies of interference from the signals produced by 35 alternator 16 and transducer 26 (or, in alternate

embodiments, transducer 24) and introduced in conductors 21 and 29 (or, in alternate embodiments, conductor 25). Additionally, conditioning circuits 79 and 38 typically place the signals produced by alternator 16 and
5 transducer 26 (or transducer 24) within a 5 V range and typically provide these signals with a generally square wave configuration which can be appropriately sampled by controller 20. Accordingly, the signals applied to controller 20 by alternator 16 (or transducer 24) and
10 transducer 26 typically have a generally square wave configuration with a frequency proportional to the rotational speed of input shaft 19 (or of engine 14) and output shaft 32, respectively.

Switch 22 has associated therewith a
15 conditioning circuit 40, which may be integral to controller 20. Depending upon the application, circuit 40 may provide signal inversion and appropriate filtering to eliminate switch bounce. However, depending upon the type of controller 20 used, circuit
20 40 may be eliminated. The signal produced by switch 22 is applied to a digital input of controller 20 via electrical conductor 23.

Hydraulic valve 28 is coupled to a digital output of controller 20 by an appropriate amplification and signal conditioning circuit 44, which may be
25 integral to controller 20, and electrical conductor 48. As will be discussed in greater detail below, controller 20 applies a signal, such as an analog or a pulse-width modulated (PWM) signal, to valve 28 via electrical
30 conductor 48 and circuit 44. Due to the nature of the solenoid that operates valve 28, amplification and isolation circuit 44 is utilized to produce a control signal having sufficient voltage and current to operate valve 28. Additionally, due to inductive kickbacks
35 which may potentially be produced by the solenoids of

valve 28, isolation may be provided in circuit 44 to protect controller 20. While controller 20 is typically configured to apply an analog current signal to valve 28, in alternative embodiments an analog voltage signal, a pulse-width modulated (PWM) current signal, or a PWM voltage signal can be similarly employed and provided to valve 28. In each case, the magnitude of the signal provided (which, in the case of a PWM current or voltage signal, is the time-average magnitude of the signal and therefore depends upon the duty cycle or pulse width of the signal) is proportional to the desired pressure from valve 28.

Turning to the operation of valve 28, valve 28 is a proportional hydraulic valve which applies hydraulic fluid to PTO clutch 18 from the system hydraulic fluid source 52 at a pressure which is related to (e.g. proportional to) the time-averaged voltage applied to the solenoid associated with valve 28. Thus, the pressure of the fluid applied to PTO clutch 18 via hydraulic conduit 36 by valve 28 may be controlled by applying a variable current signal to valve 28. In alternate embodiments, the pressure may be controlled by applying a variable voltage signal, a PWM current signal, or PWM voltage signal to valve 28. Where a PWM signal is applied to the solenoid of valve 28 to control the pressure of the hydraulic fluid applied to PTO clutch 18, the pressure of the fluid is proportional to the pulse width of the PWM signal produced by controller 20.

As discussed above, PTO clutch 18 is a multi-plate hydraulic clutch. This type of clutch is capable of transferring a torque from clutch input shaft 19 to output shaft 32, where the torque is generally proportional to the pressure of the hydraulic fluid applied to PTO clutch 18. Output shaft 32 is shown

directly coupled to 1000 RPM PTO (high speed PTO) 33 and also is shown coupled to 540 RPM PTO (low speed PTO) 35 by reduction gear 37. In alternative embodiments, high speed PTO 33 may be of another speed rating, such as
5 750 RPM. Accordingly, the torque transferred between shafts 19 and 32 will be generally proportional to the magnitude of the analog current signal applied from controller 20 to the solenoid of valve 28. (In alternate embodiments where an analog voltage signal, a
10 PWM current signal, or a PWM voltage signal is provided to valve 28, the torque transferred between shafts 19 and 32 also will be generally proportional to the magnitude of the applied signal, which in the case of a PWM signal is proportional to the duty cycle or pulse
15 width of the signal.) While, in the ideal case, it may be convenient to have the torque transferred between shafts 19 and 32 exactly proportional to the magnitude of the current signal applied to valve 28, in mechanical systems such a relationship may be difficult to obtain.
20 Accordingly, controller 20 is programmed to compensate for the inability to obtain such proportionality, and overall non-linearity in the electronics and mechanism of the control system 10.

Also shown in FIG. 1 is an implement 17 that
25 may be attached to (typically, towed by) tractor 12. Implement 17 includes equipment (not shown) that is operated by way of power from tractor 12. The equipment may perform one or more actions upon a field, such as planting or tilling. Implement 17 is capable of
30 receiving power from tractor 12 via an implement input shaft 51 coupled to high speed PTO 33 via a coupler 47. When PTO clutch 18 is engaged and is transmitting power from engine 14 to output shaft 32 and high speed PTO 33, power is also then transmitted to implement input shaft
35 51. In addition to implement input shaft 51, implement

17 also include an implement output shaft 85 that couples, and transmits power from, the implement input shaft to the equipment. Implement input shaft 51 and implement output shaft 85 are coupled via an over-
5 running clutch 87. Over-running clutch 87 allows implement output shaft 85 to continue to rotate freely even when implement input shaft 51 is not rotating, and allows the implement output shaft to rotate at a higher angular velocity than the implement input shaft. If
10 locking pins and notches (not shown) of over-running clutch 87 are not engaged, implement input shaft 51 must rotate a portion of a revolution to engage the pins with the notches before the over-running clutch will transmit power from the input shaft to implement output shaft 85.
15 Implement input shaft 51 is coupled to high speed PTO 33. In alternate embodiments, a similar implement input shaft may be coupled to low speed PTO 35 by way of a second coupler (not shown).

Referring now to FIG. 2, controller 20 is
20 depicted as including a memory circuit 54 (which may include RAM and ROM) and/or as being configured or programmed to provide the operations of a speed sensing circuit 56, a timing circuit 58, a switch status monitoring circuit 60, a signal processing circuit 62,
25 and a valve control signal output circuit 64. The direction and channels for data flow between circuits 54, 56, 57, 58, 60, 62 and 64 are shown in FIG. 2. The ROM of memory circuit 54 stores those values required for system 10 initialization and the constants required
30 for the operation of certain programs run by controller 20. The RAM of memory 54 provides the temporary digital storage required for controller 20 to execute the system program. While, at the present time, memory such as RAM and/or ROM is preferred, memory need
35 not be limited to such types, and other memory types,

including for example, chemical, optical, bubble, and biological, can also be utilized as may be appropriate.

It will be appreciated by those skilled in the art, that, although reference has been made hereinabove to various circuits and memory and to operations described and discussed with reference thereto, such referenced circuits and their operations, including operations as discussed and described hereinafter, may, in various embodiments, be considered to be encompassed within or associated with a programmed or programmable processor or microprocessor and its associated memory and input and output circuitry. In such regard, and with particular regard to various embodiments of control system 10, actions associated herein with various circuit portions of controller 20 may thus be effectively carried out or accomplished in accordance with the programming of a microprocessor or other control device or mechanism or by other devices or mechanisms so connected as to operate in a like or similar manner to perform the necessary actions.

Frequency interface circuit 57 and speed sensing circuit 56 receive signals from alternator 16 and transducer 26 that are applied to conductors 25 and 29, and convert the signals to digital values representative of the rotational speeds of engine 14 (or input shaft 19) and output shaft 32, respectively. (In alternative embodiments, speed sensing circuit 56 may receive signals from transducer 24 that are applied to conductor 25, and convert those signals to digital values representative of the rotational speed of input shaft 19, in place of or in addition to frequency interface circuit 57, alternator 16 and conductor 21.) Insofar as the output of alternator 16 is a square-wave, frequency interface circuit 57 may operate as a timing

interface that measures the time between pairs of edges of the square wave.

Timing circuit 58 includes counters which are utilized by signal processing circuit 62 while executing the programming for the engagement strategy.

Switch status monitoring circuit 60 converts the signals applied by switch 22 to conductor 23 to digital values representative of the status of these switches.

Valve control signal output circuit 64 produces an analog signal, such as an analog current signal, applied to the solenoid of valve 28 via conductor 48 and isolation circuit 44, having an appropriate magnitude.

As is briefly discussed below, the program executed by controller 20 is preferably executed at 100 Hz (although, in alternate embodiments the program could be executed at other frequencies). (In an alternate embodiment in which valve 28 is provided with a PWM current or voltage signal, valve control signal output circuit 64 would produce a 400 Hz PWM current or voltage signal having an appropriate pulse width. Assuming the same program execution frequency of 100 Hz, the pulse width of the signal from circuit 64 would be updated every 10 milliseconds or every 4 cycles of the PWM signal.)

FIGS. 3A, 3B and 3C depict a representative operational sequence of a PTO engagement and operation such as might occur with the system of the present invention, and FIG. 4 illustrates the effects of such an operational sequence. Basically, there are three sequential modes of electrical signal modulation of the PTO valve, designated as the FILL MODE, the MODULATION MODE and the RAMP MODE, which are indicated along the horizontal axis in Figure 4. The vertical axis in

FIG. 4 represents the PTO valve current in units of amps, and the horizontal axis represents time. Typically, the PTO module modulates the valve by varying analog current to the coil. Superimposed on the control
5 current is a fixed frequency dither signal. FIG. 4 is a representational figure whose purpose is to illustrate certain features, and is therefore not necessarily to scale.

I_{INIT} shown in FIG. 4 is the current level at
10 which a PTO solenoid coil is cracking the PTO valve open just enough for the PTO clutch to start carrying torque. The value of this current level comes from PTO calibration which may be predetermined or otherwise established in various ways. The value of such current
15 is typically between 200 - 400 ma.

Time t_{s1} in FIG. 4 is the time at which the PTO control current reaches I_{INIT} , typically around 500 ms.

In a more preferred form, the FILL MODE may be considered to have three identifiable stages: VALVE
20 WAKE-UP, GENTLE INCREMENT, and LOW ENERGY SHOCKS. The system is hereafter described with reference to the more preferred form of a FILL MODE, although it should be recognized that the present invention can also be employed with a more basic FILL MODE that does not
25 employ as many differentiable stages but which nevertheless effects over some time period an increase in applied torque between the input and output shafts to effect initial movement of the output shaft. Regardless of form, FILL MODE is considered to begin at t_0 with PTO
30 speed at zero when PTO switch 22 is closed and to end when PTO speed (output shaft movement) is detected, such as at T_1 . The time at which PTO speed is detected is the start of the MODULATION MODE.

In its preferred form, the FILL MODE
35 preferably starts with a VALVE WAKE-UP stage. The

waking up current is typically about 200 ma above I_{INIT} . The duration of such stage may be made to depend upon how long the PTO has been in OFF state, and may typically be set, as indicated below:

5

	<u>PTO off time</u>	<u>Wake-up duration</u>
	<= 500 msec	0
	> 500 msec	10 msec
	> 800 msec	20 msec
10	> 1200 msec	30 msec
	> 2000 msec	40 msec
	> 4000 msec	60 msec
	> 6300 msec	70 msec

15 Utilization of a VALVE WAKE-UP stage speeds up the filling up of the PTO valve and conditions the valve to be ready to carry torque.

 After valve wake-up, the current will preferably drop to a starting current value I_s which will
20 be about 40 ma below I_{INIT} and thereafter quickly enter the GENTLE INCREMENT stage. During such stage, the current keeps increasing, generally gently after, perhaps, a more pronounced initial increment, until
25 with the current to the PTO valve typically increasing by approximately 0.03 percent of maximum current every 10 ms. It has been found desirable to increment the current so that, after approximately 1.5 seconds, the applied current will typically be about 40 ma above I_{INIT} .

30 If, at any time during the FILL MODE, PTO shaft speed is detected, the FILL MODE ends and the MODULATION MODE starts.

 If PTO shaft movement occurs without appreciable engine droop or the PTO shaft speeds up
35 fairly quickly and without appreciable engine droop, the

controller recognizes such conditions as being indicative of a no load or very light load condition, which could also initially signify possible use of an over-running clutch. It has been found desirable to
5 employ an even more gentle current modulation in such instances to accommodate the possibility that an over-running clutch is associated with the output shaft, and the manner in which this accomplished will be further addressed hereinafter. On the other hand, if engine
10 droop is detected prior to output shaft movement, a heavier load is indicated. The time at which engine droop is detected, and the degree thereof, can be indicative of the heaviness of the load.

As noted above, it has been found that the
15 loading condition on the PTO can have a significant impact on the smoothness of the clutch engagement and the load on the drive train and power source. Clutch wear, fluid temperature, and fluid system pressure also impact the initial current I_{INIT} at which initial torque
20 carrying occurs and thus are also factors in the smoothness of the engagement. As a result of any combination of the above factors, if the starting current I_s is too high and/or the subsequent current values applied during the fill mode and/or the
25 modulation mode are increased too rapidly for an actual loading and other conditions on the PTO, the engagement can be rougher and/or the rotational speed of the engine can be decreased or droop to an undesirable extent, and even stall. These are undesirable occurrences as they
30 can cause problems including premature or increased wear on the clutch and other drive line components and even damage. If the starting current value I_s is too low and/or the subsequent current values during the fill mode and modulation mode are increased too slowly for an
35 actual loading condition on the PTO, that is, the actual

load condition is lighter than anticipated, then the engagement will likely be smooth, but the clutch will likely lock-up later than would be necessary.

Similarly, if the starting current value I_s is lower or
5 higher than desirable for a given load condition or combination of the above factors, the later in time during the engagement process at which determination of the existence of the condition and correction or compensation is initiated, the shorter the time
10 available for implementing the correction or compensation.

To avoid or reduce the influence or impact of factors such as those set forth above, including load conditions, clutch wear, fluid temperature and fluid
15 system pressure, and/or to adapt to or compensate or correct for such conditions, controller 20 will determine the starting current value I_s based at least in part on information stored in memory 54 relating to or derived from or determined during at least one previous engagement, particularly during the FILL MODE thereof.
20 Preferably, the information used for the determining the starting value will include the I_{INIT} current value from at least one previous engagement, and more preferably the I_{INIT} from four previous engagements can be averaged
25 and used as a reference for determining the I_s current value for the next engagement.

As an option, if I_{INIT} from the most previous engagement is beyond a predetermined range, or differs by more than a predetermined amount or in some
30 predetermined manner from I_{INIT} from the prior engagements, just the I_{INIT} value from the last engagement can be used as the reference for determining I_s for the next engagement, or just the I_{INIT} values from the previous engagements can be used.

In FIG. 3, a high level flow diagram showing generalized steps for collecting information for determining I_s according to the present invention is shown. After start block 128, at step 130 controller 20 will determine the starting current I_s . As noted above, preferably, starting current I_s will be based at least in part on an average of I_{INIT} for a number of previous engagements, preferably the last four engagements. At step 134, controller 20 determines the speed of engine 14 before clutch 18 is carrying torque. This step can occur at any time and provides a baseline under current conditions for determining if any engine droop as a result of engaging clutch 18 occurs. At step 136, after wake up, starting current I_s is applied to begin engagement. The current is then gently increased, as denoted at step 138. At steps 140 and 142, engine speed and the speed of clutch output 32 are monitored. These steps can commence prior to application of starting current I_s or later, and can be preformed in any order or simultaneously. Then, at step 144, information representative of the occurrence of the first of engine droop and output movement is saved as calibration information in memory 54. This information preferably includes I_{INIT} and can include T_{INIT} .

25 If no PTO output shaft speed has been detected after approximately 1.5 seconds, according to optional steps, the FILL MODE can then enter the LOW ENERGY SHOCKS stage.

Previously known systems, while they may have utilized a WAKE-UP stage and/or a GNETLE INCREMENT stage during FILL MODE, have not made use of a LOW ENERGY SHOCKS stage. It has been found desirable to include such a stage in the FILL MODE because some implements require the application of higher current to the valve in order to break the implement loose (e.g., frictions,

heavy static loads, etc.), but lower current to ramp up speed. However, it should be understood that the use of energy shocks is an optional procedure, and a background one that may not be evident to the operator. During the
5 LOW ENERGY SHOCKS stage, low energy shocks, such as roughly 10 Hz pulses riding the base current increment, may be applied to more readily break loose the implement and to effect movement of the output shaft. The amplitudes of such pulses preferably starts from about
10 10 ma and gradually increases to about 50 ma.

It has been found that, after approximately 3.6 seconds, the torque capacity should typically be about enough to kill the engine. If no PTO shaft speed is detected by that time, and the engine has not been
15 killed, the software will preferably stop the FILL MODE and terminate the PTO operation. The operator will then need to re-initialize the system, such as by turning the PTO switch Off and then back On to restart the PTO.

The operation of controller 20, especially
20 with regard to the more preferred form of FILL MODE, will now be described in greater detail with reference to FIGS. 3A, 3B and 3C (FIGS. 3A, 3B and 3C represent the operational steps of the program run by controller 20.) Upon system startup at step 66, controller 20
25 reads the ROM of memory circuit 54 and initializes the counter in timing circuit 58. Controller 20 also initializes those other variables and constants which may be utilized in the programming of controller 20 as it proceeds to and through step 68.

30 At step 70, controller 20 checks the digital value representative of the status of PTO on/off switch 22, such as is available from switch status monitoring circuit 60, and remains in a loop back to such step if switch 22 is not detected as being closed. Once
35 switch 22 is detected to be closed, operation will then

advance to step 88 and proceed to execute the steps required to begin (or continue) engagement of clutch 18.

At step 88, by checking the value representative of the rotational speed of output shaft 32 (analogous to step 142 in FIG. 3), controller 20 determines whether or not shaft 32 is moving, and proceeds to step 90 if the output shaft 32 is not moving or to step 124 (FIG. 3C) if the output shaft 32 is moving.

If the output shaft 32 is not moving and operation has proceeded to step 90, the system is in its FILL MODE of operation and controller 20 sets a fill current value, which is dependent, in part, upon the particular time count.

In general, at step 90 the fill current value may be set in accordance with a predetermined current/pressure control curve, such as has been discussed generally hereinabove. This includes at the commencement the FILL MODE, at a time before time T_s , for instance, at time t_0 , the step of determining a starting current I_s as indicated at step 132 of FIG. 3.

At specific times during the later LOW ENERGY SHOCKS stage, the current value will be increased so as to provide a current shock to the clutch system. By way of example, at other than the specific times for application of current shocks, controller 20 may read the time associated with the times since the PTO switch was closed, such as from a timer counter of circuit 58, and set the current magnitude value to a predetermined percentage if switch 22 has been closed less than a given time. If the time is greater than that given time, the current magnitude value may be increased by 0.1% for each 10 ms increment of time elapsed subsequent to switch 22 being closed for that given time. (In an alternative embodiment, the pulse width may be set to a

predetermined percentage (e.g. 20%) of the maximum pulse width value if switch 22 has been closed for 300 ms or less. If the time is greater than 300 ms, the pulse width value may be increased by 0.1% for each
5 10 ms increment of time elapsed subsequent to switch 22 being closed for 300 ms.)

At the specific times at which current shocks are to be applied, the current values are set to a significantly higher value than would otherwise be the
10 case. FIG. 6 is a flowchart setting forth one embodiment of a more detailed operational sequence of step 90 of FIG. 3A, showing how the current shock values, such as the increased magnitude of the current, can be set to occur at times t_{s1} , t_{s2} , t_{s3} , and t_{SN} .
15 Although only a single shock is depicted in Fig. 4 at such times, it should be appreciated that application of a series of shocks commencing at such times is also possible and preferable.

When no movement of the output shaft 32 has
20 been detected at step 88 and the engagement operation has progressed to step 90, then with particular reference to FIG. 6, at step 90A controller 20 checks whether the then-current time is time t_{s1} , the time at which a first current shock is to be applied if the
25 output shaft 32 has not commenced movement by that time. If the time t is t_{s1} , controller 20 proceeds to step 90B where it sets the current value to be used in applying the current shock at time t_{s1} before proceeding through point C of FIG. 6 to step 104 of FIG. 3A.

30 If, at step 90A, the then-current time is not equal to t_{s1} , controller 20 proceeds to step 90C where it next checks whether t is equal to t_{s2} , the time at which a second current shock is to be applied if the output shaft 32 has not commenced movement by that time. If
35 the time t is t_{s2} , controller 20 proceeds to step 90D

where it sets the current value to be used in applying the current shock at time t_{s2} before proceeding through point C of FIG. 6 to step 104 of FIG. 3A.

If, at step 90C, the then-current time is not
5 equal to t_{s2} , controller 20 proceeds to step 90E where it next checks whether t is equal to t_{s3} , the time at which a third current shock is to be applied if the output shaft 32 has not commenced movement by that time. If the time t is t_{s3} , controller 20 proceeds to step 90F
10 where it sets the current value to be used in applying the current shock at time t_{s3} before proceeding through point C of FIG. 6 to step 104 of FIG. 3A.

If, at step 90E, the then-current time is not
15 equal to t_{s3} , controller 20 can proceed to other steps such as step 90G, if the system is designed to provide additional current shocks at other times, or, if no additional current shocks are to be applied with a particular system, to step 90I. At step 90G,
20 controller 20 checks whether t is equal to t_{sN} , the time at which an Nth current shock is to be applied if the output shaft 32 has not commenced movement by that time. If the time t is t_{sN} , controller 20 proceeds to step 90H where it sets the current value to be used in applying the current shock at time t_{sN} before proceeding through
25 point C of FIG. 6 to step 104 of FIG. 3A. If t is not equal to t_{sN} at step 90G (or to a value of t at any of steps 90A, 90C, or 90E, if the system is designed to apply fewer than 2, 3, or N shocks, respectively), controller 20 proceeds to step 90I where it sets the
30 fill current value for time t in a manner such as has been previously explained hereinabove with reference to step 90 of FIG. 3A before proceeding through point C of FIG. 6 to step 104 of FIG. 3A.

FIG. 10 is another flowchart setting forth an
35 optional feature that may be included within the

operational sequence of FIG. 6, including additional steps at point A of FIG. 6, showing how a current shock value can be triggered by detection of engine droop prior to detection of movement of output shaft 32. As
5 shown in FIG. 10, upon reaching step 90 (in FIG. 3A), and before proceeding to step 90A, controller 20 may first determine whether a DROOP flag has been set. If such a flag has been previously set, the controller may proceed, for example, either to point B of FIG. 6 or to
10 step 90A of FIG. 6, depending upon particular systems.

If, however, DROOP flag has not been previously set, controller 20 proceeds to step 90K, where it checks to see if any engine droop (or a degree of engine droop) is detected. If not, controller 20
15 proceeds to step 90A on FIG. 6; if so, it proceeds to step 90L.

At step 90L, controller 20 sets the DROOP flag before proceeding to step 90M, where controller 20 saves information relating to the droop, which can include the
20 time of the occurrence of the droop and also the level of the droop, and sets a current shock valve to be applied, at $t=T_{\text{DROOP}}$, before proceeding to and through point C of FIG. 6 to step 104 of FIG. 3A.

Once the current value for time t has been set
25 at step 90, such as at steps 90B, 90D, 90F, 90H, or 90I of FIG. 6 or step 90M of FIG. 10, operation then proceeds to step 104 (FIG. 3A), which step will be further addressed at a later point hereinafter.

From the foregoing discussion and description,
30 it should be understood that a purpose of steps 88 and 90 is to effect smooth engagement of PTO clutch 18. A certain volume of hydraulic fluid must be provided to PTO clutch 18 before the clutch plates of PTO clutch 18 travel through the distance required to engage the
35 clutch plates. During a clutch filling process, it is

undesirable to apply hydraulic fluid to the clutch at a fixed or undesirably high pressure since the clutch will abruptly apply torque from input shaft 19 to output shaft 32. Such an abrupt application of torque can
5 potentially cause damage to output shaft 32 or an associated implement connected to the PTO output shaft. By initiating the filling of clutch 18 with a pressure equivalent to the pre-stress force applied by the clutch springs, and by applying current to the valve to effect
10 a controlled filling of clutch 18, the clutch plates can be made to move relatively slowly toward engagement, and the pressure can be controllably increased gradually until engagement. This process prevents the abrupt transfer of torque from input shaft 19 to output
15 shaft 32.

As is depicted in a somewhat idealized form in FIG. 4, following valve wake-up at time t_0 , the current/pressure applied over time from T_s starts at a lower starting level I_s and increases in accordance with
20 the current fill values established at step 90 until time T_1 , when the first motion of the output shaft 32 occurs and is detected at step 88. During the period between t_0 and T_1 , at times t_{s1} , t_{s2} , and t_{s3} , current shocks are shown as having been applied, consistent with
25 current values as set at steps 90B, 90D, and 90E. As shown in FIG. 4, application of the current shocks need not occur at equally spaced intervals from one another, but can occur at times selected for and matched to particular systems. As has previously been noted,
30 during such time period from t_0 to T_1 , following initial application of current of a given magnitude for a short duration, it has been found to be advantageous to gradually increment the current, such as by approximately 0.03 percent of maximum current every
35 10 ms, until motion of the output shaft 32 is detected.

As has previously been explained, the current shocks provide a higher magnitude of current for brief durations at the times of their application.

In alternative embodiments employing PWM
5 signals, the pulse width of the PWM signal may be initiated at a certain duty cycle (e.g. 20%) at time t_0 and increased in gradual steps until output shaft 32 begins moving as determined at step 88. At the times when a current shock is to be applied, the pulse width
10 may be expanded to achieve the short duration pressure shock desired at the PTO clutch 18.

Referring now again to FIG. 3A, as has previously been discussed, once the fill current has been set, controller 20 proceeds from step 90 of FIG. 3A
15 to step 104. At step 104, controller 20 checks if the timer has timed out. If so, controller 20 proceeds to step 107 and terminates the PTO operation; if not, it proceeds directly to step 106.

At step 106, controller 20 operates to send
20 the established current value to PTO clutch valve 28 before proceeding to step 109, where it updates the timer before proceeding to step 110. At step 110, controller 20 checks to see if the PTO switch is still closed. If not, controller 20 proceeds to step 107,
25 where the PTO operation is terminated. If the switch is still closed, however, controller 20 proceeds to step 108, which identifies a return to step 88 and commencement of another loop of the engagement operation. (At step 106, for embodiments that use PWM
30 techniques, controller 20 may effect application of a pulse width modulated signal to valve 28 via conductor 48 at a frequency of 400 Hz with a pulse width corresponding to the current pulse width value as set in that particular loop through the operation sequence.)

It will be appreciated that various checks and actions may be associated with RETURN 108 for effecting a conclusion of the operational sequence and cessation of further looping through the sequence, and for
5 securing information or initializing values for further activities, depending upon the system. By way of example, previous speed values for the input and/or output shafts may be saved for future reference, if desired, and new speed values may be read at such step
10 for reference and use upon return of the operation to step 88 and successive steps.

It should be understood that the foregoing discussion has now described the loop operation from step 88 through RETURN step 108 and back to step 88,
15 which looping operation occurs during the FILL MODE. The controller 20 causes the timer counter to be updated by a specified amount upon each passage through step 109, which amount is related to the time it takes to cycle through the operational loop. (For the
20 programming represented by the flow charts of FIGS. 3A, 3B and 3C), running at a rate of approximately 100 Hz, one cycle is approximately 10 ms. Accordingly, for one cycle, the counter is updated by a count value associated with 10 ms.)

25 Referring again to FIG. 3A, upon a looping pass through step 88, if shaft 32 is detected to be (already) moving, FILL MODE ceases and system operation enters (or continues) with either the MODULATION MODE or RAMP MODE of operation as controller 20 proceeds to
30 step 124 (FIG. 3C) instead of to step 90.

At step 124, if the engine droop flag has been set, controller 20 proceeds through point B of FIGS. 3A and 3B to step 76 of FIG. 3B. If the engine droop flag has not been set, controller 20 proceeds to step 91 to
35 determine if the movement detected at step 88 is the

first movement of the output shaft. If not, controller 20 proceeds through point B of FIGS. 3A and 3B to step 76 of FIG. 3B. If the movement is the first movement, the MODULATION MODE commences and controller 20 proceeds
5 to step 93 where it saves the time of such detected movement as TIMER1, resets and starts a timer for TIMER2, and sets a 1ST TIME flag before proceeding to step 120. The saving of the value of the current at which the first movement is detected and the time
10 thereof corresponds to step 144 of FIG. 3. If the detected movement is not the first movement of the output shaft, controller 20 instead proceeds through point B of FIGS. 3A and 3B to step 76 of FIG. 3B.

If the movement detected at step 91 is the
15 first movement and operation has proceeded through step 93 to step 120, at step 120 controller 20 checks to see if engine droop (or a degree of engine droop) has occurred at that time. Typically this may take the form of determining whether the difference between a previous
20 (nominal) engine speed value and the current engine speed value is within or without an established deviation value. If the difference exceeds the established deviation value, such finding is indicative of the application of a significant enough load to the
25 engine as the output shaft begins to move that the load is considered to be other than a very light load or an associated over-running clutch. In such instance, controller 20 proceeds through point B of FIGS. 3A and 3B to step 76 of FIG. 3B. On the other hand, if the
30 difference is within the deviation value, such finding is considered indicative of the existence of either or very light load or an associated over-running clutch, and controller 20 then proceeds to step 122.

At step 122, controller 20 sets a VERY LIGHT LOAD status flag before proceeding through point B of FIGS. 3A and 3B to step 76 of FIG. 3B.

5 The lack of engine droop detected at step 120 when first movement of the output shaft is detected at
10 step 91 is significant because such determinations, in combination, identify reactions encountered when the load that is applied is very light or when an over-running clutch has been encountered and the locking pins
15 of such over-running clutch have not yet engaged the locking notches of such over-running clutch, in which situations the initially detected load on the PTO output shaft presents little initial resistance to the applied torque through the PTO clutch and little loading of the engine.

Detection of movement of the output shaft at step 88 and determination of first movement at step 91 is significant because such actions identify the conclusion of the FILL MODE and the commencement of the
20 MODULATION MODE. As is depicted on FIG. 4, MODULATION MODE directly follows the FILL MODE and is initiated when PTO speed (output shaft movement) is first detected. After detection at T_1 of PTO shaft speed, controller 20 modifies the analog command signal to the
25 valve based on acceleration of the PTO clutch until PTO CLUTCH LOCK-UP occurs (i.e., when PTO clutch slip meets the criteria for a locked clutch condition) at T_L .

In general, during the period between PTO speed detection and clutch lock-up, the analog command
30 signal is typically adjusted depending upon the relationship between the calculated acceleration of the PTO clutch compared to the target acceleration value. Controller 20 monitors engine rpm and typically assumes it will be constant for the next 2 seconds. From engine
35 speed, the controller then typically calculates the PTO

acceleration required to achieve PTO clutch lock-up within approximately 1.8 seconds. If the acceleration is lower than the target acceleration value, the control current will be increased accordingly unless the engine
5 rpm has been loaded too low. If the acceleration is higher than the target acceleration value, the control current will be decreased accordingly in the early stage of modulation. Typically, if modulation has been in process for over 1 second, or the PTO has been turned on
10 for over 4 seconds, or the clutch slippage is less than 50%, the control current will not be decreased even if the acceleration is higher than the target acceleration value, although these features may be altered depending upon particular systems and users.

15 A recognized difficulty with such procedure is that the engine speed will rarely, if ever, remain constant for 2 seconds, but will, in actuality, vary over such time, perhaps drastically, as would be the case when an associated over-running clutch locks up
20 after a short period of lock-up delay. As noted above, if output shaft movement occurs without appreciable engine droop or the PTO shaft speeds up fairly quickly and without appreciable engine droop, the controller recognizes such conditions (such as at steps 120 and
25 122) as being indicative of a no load or very light load condition, which could also initially signify possible use of an over-running clutch. It has been found desirable to employ an even more gentle current modulation in such instances to accommodate the
30 possibility that an over-running clutch is associated with the output shaft, and the manner in which this accomplished will be further addressed hereinafter.

With the foregoing in mind, when operation proceeds to step 76 of FIG. 3B, controller 20 obtains
35 the digital values representative of the rotational

speeds of input shaft 19 (or engine 14) and output shaft 32 (which may be the some of the same values as utilized in steps 88 and 120), such as provided to signal processing circuit 62 from circuits 56 and 57, and proceeds to step 78, where it then compares the speeds of shaft 19 (or engine 14) and shaft 32, and, depending upon such comparison, proceeds either to step 80 or step 82.

If the shaft speeds are the same (or are within some degree of tolerance of the speeds or proportions thereof), signifying that PTO clutch lock-up has occurred, as will be further discussed hereinafter, MODULATION MODE terminates, RAMP MODE commences, and operation proceeds to step 80.

However, if, at step 78, the shaft speeds are not the same (or are not within some degree of tolerance of the speeds or proportions thereof), which is the expected situation when output shaft movement is first detected and MODULATION MODE commences, operation proceeds instead to step 82, where controller 20 checks to see whether or not the STEADY STATE flag has been set, (signifying that PTO clutch lock-up had previously occurred). During MODULATION MODE, the STEADY STATE flag will not as yet have been set and controller 20 will therefore proceed to step 94.

The tolerance level at step 78 may be dependent, in part, upon the Time2 value reset at step 93 and may be set to such a level to ensure, for example, in the case of an associated over-running clutch, that speeds will not be considered the same during a possible lock-up delay period of the associated over-running clutch. Alternatively, controller 20 could be configured or programmed to bypass steps 76, 78, and 82 and to instead proceed directly to step 94 for a short but sufficient period of time following the

setting of the VERY LIGHT LOAD status flag in order to ensure completion of any lock-up delay period before a determination is made at step 78 that the speeds of the input and output shafts of the PTO clutch have been
5 equalized.

At step 94, controller 20 then sets a desired acceleration, which acceleration may, in some instances and with certain embodiments, be calculated once, upon a first pass through step 94 during a PTO engagement
10 operation and thereafter relied upon in subsequent passes through step 94 during such engagement operation, and in other instances and with other embodiments, be recalculated in subsequent passes through step 94 in an engagement operation. By way of example, the desired
15 acceleration, whether calculated once or multiple times, may be calculated such as by dividing the speed of the input shaft 19 at the time of calculation by 2 seconds.

In general, the first pass through step 94 is the start of the process for controlling clutch 18 to
20 accelerate output shaft 32 relative to input shaft 19 until the speed of output shaft 32 reaches its steady state speed (no clutch 18 slip) which equals or is proportional to the speed of input shaft 19. The desired acceleration of output shaft 32 at step 94 is
25 preferably calculated based upon approximately 1.8-2.0 seconds, which has been selected, based upon experimentation, to generally provide optimum acceleration of output shaft 32. However, depending upon the system configuration, such time period may be
30 varied according to the particular tractor and PTO application. The calculated acceleration serves as a reference for accelerating output shaft 32 relative to input shaft 19 at step 96.

It will be appreciated that by selecting a
35 longer acceleration period a flatter, more gentle

control curve can be obtained and that by selecting a shorter acceleration period a steeper control curve can be obtained. With this in mind, it will also be appreciated that use of a flatter, more gentle control
5 curve instead of a steeper control curve is initially desirable for certain extreme load situations, such as when an associated over-running clutch is employed. because it will allow a slower acceleration during the lock-up delay period and a consequent less abrupt
10 reaction when the over-running clutch locks up and the "true" load is absorbed by the engine. One manner of addressing the possibility of an over-running clutch in a detected very light load situation is thus to establish, at least initially, a flatter, more gentle
15 control curve during the MODULATION MODE than would otherwise be provided. Further discussion of how this is accomplished with the present invention will be provided hereinafter.

As is apparent from FIGS. 3A, 3B and 3C, and
20 as will be readily understood by those skilled in the art, and as is discussed and described in U.S. Patent No. 6,267,189, the PTO clutch control system can repeatedly set a new, updated desired acceleration as it passes through step 94. As is evident from a study of
25 FIGS. 3A, 3B and 3C, so long as the speeds of input shaft 19 and output shaft 32 remain different (as determined in step 78), the control system program repeatedly cycles through step 94. In embodiments in which the desired acceleration is recalculated each time
30 the PTO clutch control system cycles through step 94 (instead of only the first time), the desired acceleration may be repeatedly calculated by dividing the current speed of shaft 19, or another quantity related to engine speed, by the desired time of
35 engagement, which is preferably, partly for convenience

of discussion, 1.8-2.0 seconds in various of the
embodiments and related figures described and discussed
herein. Although in alternate embodiments the frequency
of recalculation may vary (or the recalculation may
5 occur at a frequency less than the frequency at which
the control system program cycles through step 94), it
has been found desirable to have the desired
acceleration recalculated at the same frequency as the
control system program cycles through step 94, which (as
10 stated above) is approximately 10 ms. Such recalculation
occurs with sufficient rapidity that the desired
acceleration is effectively continuously recalculated to
reflect changes in the speed of input shaft 19 (that is,
changes in engine speed).

15 Referring to FIG. 8, examples of the desired
and actual speeds for output shaft 32 (i.e., PTO speed),
and engine speed (i.e., the speed of input shaft 19), as
measured or determined by the PTO clutch control system
of an embodiment that recalculates the current desired
20 acceleration during the engagement operation, are
plotted against time. Four desired speed curves are
shown. The four speed curves are determined based upon
the engine speed (or speed of input shaft 19) as
measured at four times, t_a , t_b , t_c , and t_d and are labeled
25 as, and referred to below as, respectively, the "desired
PTO speed #a", "desired PTO speed #b", "desired PTO
speed #c" and "desired PTO speed #d" curves. For
convenience, only four desired speed curves are shown in
FIG. 8. As discussed above, the desired accelerations
30 in the present embodiment are actually recalculated
approximately every 10 ms (effectively continuously),
and so FIG. 8 is meant to be a symbolic description of
the actual operation of the PTO clutch control system,
in which there are many more than four desired speed
35 curves. Also, it is for generality that the four desired

speed curves are shown as being calculated at four times
(times $t_a - t_d$) that are not equidistant from one
another. Although alternative embodiments may vary, it
has been found desirable to have the desired
5 accelerations (in contrast to FIG. 8) recalculated at a
constant frequency as the PTO clutch control system
repeatedly cycles through step 94.

Although, for convenience of discussion, the
speed curves are shown as being calculated based upon
10 the same time period (from t_a to t_e), it should be
understood and appreciated that the speed curves could
be based upon different periods, and that the basic
principle relating to recalculation would still be
applicable, and that the particular time periods used
15 for the speed curve calculations may be varied and
dependent upon various factors, including such factors
as the time t of calculation or load type, for example.

As is depicted in FIG. 8, output shaft 32
begins to rotate at time t_a , and the speed of the output
20 shaft equals the speed of input shaft 19 (or the engine
speed) at time t_e (lock-up), which corresponds to T_L of
FIG. 4. Also, as shown, the speed of input shaft 19
(and of engine 14) does not remain constant as power
begins to be transferred to output shaft 32, but,
25 instead, decreases or droops. Consequently if the
actual speed of output shaft 32 were to increase in
accordance with the desired PTO speed #a curve, which is
determined based upon the initial engine speed at time
 t_a , the shaft would attain the speed of input shaft 19
30 (i.e., the engine speed) in a time significantly shorter
than the desired time of engagement (the time interval
between times t_a and t_e , i.e., 2 seconds). Instead of
attaining the speed of input shaft 19 at time t_e , the
shaft would attain the speed of the input shaft at the

time at which, as shown in FIG. 8, the desired PTO speed #a curve crosses the engine speed curve.

The embodiments that repeatedly recalculate the desired acceleration avoid this excessive engagement rate by adjusting the desired speed curve as engine speed decreases. As shown in FIG. 8, at times t_b , t_c , and t_d the desired acceleration is recalculated (at step 94 of the control system program) and the desired speed curve changes, respectively, to the desired PTO speed #b, desired PTO speed #c, and desired PTO speed #d curves. As described below, with such embodiments the actual acceleration of output shaft 32 is adjusted as the desired speed curve changes (more specifically, the actual acceleration is adjusted based upon the difference between the actual and desired accelerations). Insofar as the actual acceleration of output shaft 32 is adjusted to reflect the new desired speed curves, the output shaft speed increases at a rate such that it will approach the speed of input shaft 19 (i.e., the engine speed) at approximately t_e (i.e., within the desired time of engagement, i.e., 2 seconds), as shown in FIG. 8, and not substantially before t_e .

From all of the foregoing, it will be appreciated that it is advantageous to be able to utilize different acceleration control curves depending upon the type of load that the PTO is driving. FIG. 9 is a flowchart depicting in greater detail one manner in which this can be accomplished at step 94 in the engagement operation process, not only for very light loads and over-running clutches, but also for other types of loads such as may be establishable, particularly through the use of or in association with the application of current shocks during the FILL MODE.

During MODULATION MODE, controller 20, upon reaching step 94, will, at step 94A, check to determine

if any load flags have already been set, such as the VERY LIGHT LOAD status flag set at step 122. If so, controller 20 proceeds to step 94K; if not, it will proceed instead to step 94B.

5 At step 94B, controller 20 checks whether the saved TIMER1 value is less than t_{s1} , the time at which the first current shock was to be applied. If so, the output shaft 32 commenced movement before the scheduled time for the first current shock, as a consequence of
10 which the load is therefore classified as or considered to be a light load, and controller 20 proceeds to step 94C, where it sets a LIGHT LOAD flag before proceeding to step 94K.

 If, at step 94B, the saved TIMER1 value is not
15 less than t_{s1} , controller 20 proceeds to step 94D, where it checks whether the TIMER1 value is less than t_{s2} , the time at which the second current shock was to be applied. If so, the output shaft 32 commenced movement after the scheduled time for the first current shock but
20 before the scheduled time for the second current shock, as a consequence of which the load is therefore classified as or considered to be a medium load, and controller 20 proceeds to step 94E, where it sets a MEDIUM LOAD flag before proceeding to step 94K.

25 If, at step 94D, the saved TIMER1 value is not less than t_{s2} , controller 20 proceeds to step 94F, where it checks whether the TIMER1 value is less than t_{s3} , the time at which the third current shock was to be applied. If so, the output shaft 32 commenced movement after the
30 scheduled time for the second current shock but before the scheduled time for the third current shock, as a consequence of which the load is therefore classified as or considered to be a heavy load, and controller 20 proceeds to step 94G, where it sets a HEAVY LOAD flag
35 before proceeding to step 94K.

If, at step 94F, the TIMER1 value is not less than t_{s3} , controller 20 can proceed to other steps such as step 94H, if the system is designed to categorize additional load types, or, if no additional load types are to be categorized with a particular system, to step 94K. At step 94H, controller 20 checks whether the TIMER1 value is less than t_{SN} , the time at which the Nth current shock was applied. If so, the output shaft 32 commenced movement after the scheduled time for the (N-1)th current shock but before the scheduled time for the Nth current shock, as a consequence of which the load is therefore classified as or considered to be, for example, a very heavy load, and controller 20 proceeds to step 94I, where it sets a VERY HEABY LOAD flag before proceeding to step 94K.

If, at step 94H, the TIMER1 value is not less than t_{SN} , the load is classified as or considered to be, for example, an extreme load, and controller 20 proceeds to step 94J, where its sets an EXTREME LOAD flag before proceeding to step 94K.

Upon reaching step 94K, controller 20 then determines the desired acceleration for the load type being driven, such as in the manners previously described relative to step 94 of FIG. 3B or by alternative manners, before proceeding to step 96 of FIG. 3B. Such alternative manners, by way of example, could include the use of a preset curve for one or more load types or control curves included within look-up tables, as well as control curves determined or established by various means in real-time.

At step 96, controller 20 checks to determine whether the output shaft acceleration is less than the desired acceleration that was set at step 94. In order to perform such check, the then-current shaft acceleration must be first calculated, such as based

upon the speed of shaft 32 available from circuit 56 at that time and the speed of shaft 32 as monitored during the previous loop and stored in memory, such as at step 76. If an operational loop through step 96 is
5 executed every 10 ms, the shaft acceleration is then the change in shaft speed between program loops divided by 10 ms.

If, at step 96, the actual calculated acceleration of shaft 32 is less than the desired shaft
10 acceleration as set at step 94, operation proceeds to step 98. On the other hand, if the actual calculated acceleration of shaft 32 is greater than or equal to the desired shaft acceleration as set at step 94, operation proceeds to step 99, instead, where the current is
15 limited, before proceeding to step 100.

If the actual acceleration of output shaft 32 is less than the desired shaft acceleration and operation has proceeded to step 98, controller 20 then operates to increase the magnitude of the current. The
20 particular manner in which current magnitude changes may vary for different control system embodiments.

At step 98, a first control system embodiment (here referred to as the "unmodified PTO clutch control system embodiment") may, whenever the desired
25 acceleration exceeds the actual acceleration, increase the current magnitude by 0.1%.

An alternate second control system embodiment (here referred to as the "modified PTO clutch control system embodiment") may employ a proportional (more
30 accurately, pseudo-proportional) adjustment algorithm to determine the increase in current. In accordance with such an algorithm, the control system may operate (a) if the actual acceleration of the PTO is determined to be less than the desired acceleration but greater than two-
35 thirds of the desired acceleration, to apply current so

as to increase the torque transmitted by the PTO clutch at a slow rate; (b) if the actual acceleration of the PTO is determined to be less than two-thirds of the desired acceleration but greater than one-third of the desired acceleration, to apply current so as to increase the torque transmitted at a medium rate; and (c) if the actual acceleration of the PTO is determined to be less than one-third of the desired acceleration, to apply current so as to increase the torque transmitted at a fast rate.

A third control system embodiment (here referred to as the "modified proportional adjustment algorithm PTO clutch control system embodiment") has also been found to be practical and useful. FIG. 7 is a flowchart depicting the operational flow of one embodiment of the functionality of step 98 of the flowchart of FIG. 3B for a modified proportional adjustment algorithm PTO clutch control system embodiment. At step 98a, controller 20 determines if the actual acceleration is between the desired acceleration and two-thirds of the desired acceleration. If so, the program increases the current magnitude at a slow rate in step 98d before exiting step 98. If not, controller 20 proceeds to step 98b, at which it determines whether the actual acceleration is between two-thirds of the desired acceleration and one-third of the desired acceleration. If so, controller 20 increases the current magnitude at a medium rate in step 98e. If not, controller 20 proceeds to step 98c, at which it determines whether the actual acceleration is between one-third of the desired acceleration and one-sixth of the desired acceleration. If so, controller 20 increases the current magnitude at a fast rate in step 98f. If not, the actual acceleration is between zero and one-sixth of the desired acceleration,

and controller 20 proceeds to step 98g at which it increases the current magnitude at a slow rate. (It should be noted that the program may be designed to treat actual accelerations that exactly equal two-thirds, one-third, or one-sixth of the desired acceleration as if the actual accelerations were above or below these levels.)

A significant characteristic of the modified proportional adjustment algorithm is that the modified proportional adjustment algorithm (a) determines whether the actual acceleration is below a minimum threshold proportion of the desired acceleration, and (b) increases the current magnitude at a slow rate if the actual acceleration is below the minimum threshold proportion even though the actual acceleration is significantly less than the desired acceleration. That is, in such an embodiment, the modified proportional adjustment algorithm determines in step 98c whether the actual acceleration is below one-sixth of the desired acceleration and, if so, increases the current magnitude at a slow rate in step 98g.

This feature of the modified proportional adjustment algorithm alleviates problems such as are described in U.S. Patent No. 6,267,189 that are associated with possible spurious rotations of output shaft 32 due to premature delivery of torque by PTO clutch 18 (before the clutch is fully engaged) that may occur, for example, before over-running clutch 87 is locked. This is because, typically, once PTO clutch 18 is engaged and output shaft 32 is being accelerated, the output shaft would not have an actual acceleration less than one-sixth of the desired acceleration. Further, typically, PTO clutch 18 is not capable of delivering sufficient torque when the clutch is not fully engaged so as to cause output shaft 32 to accelerate at a rate

greater than one-sixth of any of the desired accelerations that may be calculated by control system 10. Therefore, the modified proportional adjustment algorithm fulfills the two goals of (a) causing the current magnitude to increase at a fast rate when the actual acceleration of output shaft 32 is significantly less than the desired acceleration and yet (b) not causing the current magnitude to increase at a fast rate when PTO clutch 18 is still not fully engaged.

While, in such an embodiment, the ratios of actual acceleration to desired acceleration that determine the current magnitude increase rates are preferably set at two-thirds, one-third, and one-sixth, in alternate embodiments the ratios may be set at different levels. Indeed, different PTO clutch control systems may have a variety of different proportional adjustment algorithms that distinguish among more (or less) than four ranges (of ratios of actual acceleration to desired acceleration) and in which the control systems provide finer (or less fine) gradations of increases in the current magnitude. (Fully proportional control may also be appropriate in certain embodiments.) Also, the exact values for the "slow", "medium", and "fast" rates of current increase may vary depending upon the embodiment, although the "fast" rate of increase will typically be the fastest rate at which the mechanical clutch can predictably increase torque in response to commands from the control system to increase pressure. It should be noted that, while such an embodiment of the invention combines both the functionality of the modified proportional adjustment algorithm and the above-described repeated (continuous) recalculation of the desired acceleration (and modification of the desired speed curve), the modified proportional adjustment algorithm of step 98 may be

employed even when the desired acceleration is only calculated once.

Although the foregoing discussion of steps 96 and 98 has focused on embodiments that make use of increases in current magnitude in engagement operations, 5 embodiments that make use of increases in pulse width may also be employed. With such embodiments, if, at step 96, the actual acceleration of output shaft 32 is determined to be greater than or equal to the desired 10 acceleration, the controller 20 proceeds to step 100, leaving the pulse width value unchanged. If, at step 96, the actual acceleration of output shaft 32 is determined to be less than the desired acceleration, the controller 20 proceeds instead to step 98, at which it 15 operates to increase the current pulse width by 0.1%.

In certain of such systems, it may be desirable to reduce the pulse width value when the actual acceleration of output shaft 32 is greater than the desired acceleration. However, this type of control 20 may cause hunting, and thus an acceleration of shaft 32 which is not smooth. Accordingly, in the presently preferred embodiments that utilize pulse width modulation techniques, it is considered preferable to leave the pulse width value unchanged when the actual 25 acceleration of shaft 32 exceeds the desired acceleration. With such embodiments, a pulse width increase of 0.1% for each 10 ms interval (i.e., for each pass through step 98) has been found to be advantageous and preferable.

30 Any of these control system embodiments (or the programming contained therein) may be advantageously employed in conjunction with the control system described above in which the desired accelerations are repeatedly recalculated (i.e., such that the desired 35 speed curve changes with engine speed).

Regardless of the particular embodiment, when the engagement operation reaches step 100 from either step 98 or step 99, controller 20 checks whether the increased current value, as set at steps 98, 99, or 102, exceeds the maximum allowable current value. If so, controller 20 proceeds to step 101 and resets the current value to the maximum allowable value before proceeding through point A of FIGS. 3B and 3A to step 104 of FIG. 3A; if not controller 20 proceeds directly through point A of FIGS. 3B and 3A to step 104 of FIG. 3A.

Operation then proceeds in the manner previously described commencing at step 104 and continues in a MODULATION MODE operational loop until, at step 78 of FIG. 3B, the speeds are detected as being the same. At that time, MODULATION MODE ceases and RAMP MODE commences.

Operation then proceeds from step 78 to step 80, instead of to step 82, and at step 80 controller 20 then resets the timer count and also sets a STEADY STATE flag before proceeding to step 102. At step 102 controller 20 determines a current value to be applied, which, during RAMP MODE, may include incremental increases to the current value, such as by increasing the current magnitude by 1.00% (or, in alternative embodiments, increasing the pulse width value by 1.00%), before proceeding to step 100.

Upon completion of step 102, controller 20 proceeds to step 100, and operation continues therethrough and thereafter as previously described, with continuing operational looping through steps 80 and 102 of the RAMP MODE loop.

After the maximum current value is reached (at T_{max}) in continuing passes through step 102, RAMP MODE is

completed, and steps 100 and 101 act to limit the current value to the maximum current value.

If, in operational passes after the STEADY STATE flag has been set at step 80, speeds are
5 subsequently found to (again) be different at step 78, controller 20 proceeds to step 82, where it checks to see if the STEADY STATE flag is set. Since the flag has previously been set, controller 20 proceeds to step 83.

At step 83, controller 20 determines whether
10 or not the speed difference between shaft 19 (or engine 14) and shaft 32 is greater than some allowable deviation value, such as fifteen percent (15%). If the speed difference is greater than fifteen percent (15%), operation proceeds to step 85, which is indicative of a
15 fault condition and results in termination of PTO operation. If the speed difference is less than 15%, controller 20 proceeds instead to step 102, from which point the operation will proceed as previously described. Typically, if the STEADY STATE flag has
20 previously been set and step 102 is reached from step 83, the determined current value will be set at or near to the maximum allowable current value.

Referring now to FIGS. 4 and 5 relative to the foregoing discussion, it should be observed that PTO
25 clutch lockup occurs at time T_L when the speeds of input shaft 19 (or engine 14) and output shaft 32 become equal or proportional, as detected at step 78 of FIG. 3B. Following such occurrence, so long as the speeds remain the same, operation sequence controller 20 repeatedly
30 proceeds through steps 102 and 100, increasing the current value with each pass through step 102, until the current value exceeds the maximum allowable current. At that point, and in subsequent passes through step 100, the current value is reset to the maximum allowable
35 current value at step 101. Such actions cause the

current value to be ramped up over time to produce a clutch pressure in PTO clutch 18 associated with the maximum allowable torque to be transmitted between input shaft 19 and output shaft 32. If the current value ever
5 becomes greater than the maximum allowable current value, the current value is reset to the maximum allowable current value at step 101.

For embodiments that utilize PWM techniques, following lockup at time T_L controller 20 proceeds
10 through steps 100 and 102 to ramp up the pulse width value to produce a clutch pressure in clutch 18 associated with the maximum torque to be transmitted between shafts 32 and 19. In step 100, the current pulse width value is compared with the maximum pulse
15 width value. If the current pulse width value set at steps 98, 99, or 102 is greater than the maximum pulse width value, controller 20 resets the pulse width value to the maximum pulse width value at step 101.

It should be recalled from discussions
20 hereinabove that differing time limits may be established or utilized for different modes of the operation and that the timer is updated at step 109 of FIG. 3A as the looping operations proceed, as a consequence of which detection of a timing out of the
25 timer at step 104 by the controller 20 may occur under several different circumstances.

In such regard, it should be recalled that one manner of reaching step 104 is through on operational loop including step 90. At step 90 the fill current
30 value is set when output shaft 32 is detected as not moving at step 88. If, after operational looping during FILL MODE for a certain time, the output shaft 32 has not yet begun moving, controller 20 thus operates at step 104 to terminate the PTO operation.

Another manner in which step 104 can be reached is through an operational loop including steps 94, 96, and 98 or 99. If, after commencement of MODULATION MODE, the speeds of the input shaft 19 and the output shaft are not found to be the same at step 78 within a given time, lockup of the clutch has not occurred within that time, and controller 20 again operates at step 104 to terminate the PTO operation.

A further manner in which step 104 can be reached is through an operational loop including step 102. During RAMP MODE, so long as the speeds of the input and output shafts are the same, the timer is reset upon each passage through step 80. If the speeds differ at some point, however, operation will proceed through step 82 to step 83, instead of to step 80, and the timer will not be reset at step 80 in that loop. In continuing passes through a loop that includes step 83 instead of step 80, the timer will be repeatedly updated at step 109 (FIG. 3A) until either (a) the speeds are again found to be the same at step 78, and the timer is reset at step 80, or (b) the time limit for again achieving the same speeds is reached at step 104 (with such condition typically being indicative of undesirable slippage in the PTO clutch 18), resulting in termination of the PTO operation at step 107, or (c) detection of a fault condition at step 83, resulting in termination of the PTO operation at step 85.

In addition to the various checks performed and conditions tested, as discussed and described in the foregoing, additional checks and tests may be desirable with various systems, including, by way of example, periodic tests of engine speed and other operational factors or considerations, and the outcomes of such tests may be utilized in determining the course of

operations without departing from the spirit and scope of the present invention.

Although various features of the control system are described and illustrated in the drawings, 5 the present invention is not necessarily limited to these features and may encompass other features disclosed both individually and in various combinations. For example, developments in PTO clutches may make electric clutches cost effective for PTO applications. 10 Accordingly, hydraulic clutch 18 and control valve 28 may potentially be replaced with an associated electric clutch and electric clutch control circuit.

It will be understood that changes in the details, materials, steps, and arrangements of parts 15 which have been described and illustrated to explain the nature of the invention will occur to and may be made by those skilled in the art upon a reading of this disclosure within the principles and scope of the invention. The foregoing description illustrates the 20 preferred embodiment of the invention; however, concepts, as based upon the description, may be employed in other embodiments without departing from the scope of the invention. Accordingly, the following claims are intended to protect the invention broadly as well as in 25 the specific form shown.